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SUSY-GUT HIGGS PROBE AT FUTURE e^+e^- COLLIDERS [1]

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Abstract

Several independent constraints on the minimal supersymmetric model with constraints from grand unifications and cosmology select the region of low-energy supersymmetry below $\mathcal{O}(1\ \text{TeV})$. The resulting mass of the lightest Higgs boson can probably be covered at LEP II only if its beam energy exceeds 200 GeV, and is within the detectability range of the NLC with $\sqrt{s} = 300$ GeV.

Supersymmetry and grand unifications have recently gained renewed interest stemming from LEP measurements of the gauge couplings. The running couplings do not meet at one point in the Standard Model, while they do so in minimal supersymmetry [1]. This remarkable feature, along with its several other virtues, makes supersymmetry a particularly attractive extension of the Standard Model. Several of those desirable features are simultaneously satisfied [2, 3] in minimal supersymmetry for energy scales below roughly 1 TeV. The resulting region of the parameter space puts stringent constraints on the mass spectra of supersymmetric particles. In this report [3] I briefly describe the resulting implications for the lightest Higgs boson searches at future e^+e^- colliders, like LEP II and the NLC.

I consider the minimal supersymmetric model coupled to minimal supergravity which provides the desired form of SUSY soft breaking terms. The main unification assumptions of the minimal SUSY model coupled to minimal supergravity are as follows:

[1] Talk at the *Workshop on Physics and Experiments with Linear e^+e^- Colliders*, Waikaloa, Hawaii, April 26-30, 1993, to appear in the Proceedings.

1. *Common gauge coupling g_{GUT}:* The three running gauge couplings meet at a single energy scale M_{GUT}: $g_1(M_{GUT}) = g_2(M_{GUT}) = g_s(M_{GUT}) = g_{GUT}$, where $g_1 = \sqrt{3/5}g'$.

2. *Common gaugino mass $m_{1/2}$:* The soft SUSY breaking gaugino mass terms satisfy $M_1(M_{GUT}) = M_2(M_{GUT}) = M_3(M_{GUT}) = m_{1/2}$.

3. *Common scalar mass m_0:* The soft SUSY breaking scalar mass terms contributing to the squark, slepton, and Higgs masses are equal to m_0 at M_{GUT}.

4. *Common trilinear scalar coupling A_0:* The soft trilinear SUSY breaking terms are all equal to A_0 at M_{GUT}.

The bilinear soft scalar coupling B_0 is sometimes assumed to be related to A_0 via $B_0{=}A_0 - 1$ but in general remains an independent parameter.

In addition one often assumes that at M_{GUT} the masses of the down-type quarks and leptons of each generation are equal since in many GUTs they appear in the same multiplets. We find, however, that if we assume $h_b(M_{GUT}) = h_\tau(M_{GUT})$ but ignore GUT-scale threshold corrections then the resulting values of m_b are some 20% (~ 1 GeV) too high [3]. On the other hand, even rather small (few per cent) GUT-scale corrections to the running of h_b result in typically larger shifts in $m_b(m_b)$ [3]. In light of this and since we do not adhere to any specific GUT model, at this point we do not include this constraint in limiting the allowed parameter space. On the other hand, we do not find the GUT-scale effects on the running of the gauge couplings and various mass parameters equally important and we ignore them.

Thus in this model there are at least six fundamental quantities: (a) the common gaugino mass $m_{1/2}$, (b) the common scalar mass m_0, (c) the Higgs/higgsino mass parameter μ, (d) the common scale $A_0 m_0$ of all the trilinear soft SUSY-breaking terms, (e) the bilinear soft mass parameter $B_0 m_0$, and (f) the top Yukawa coupling h_t. Two minimization conditions of the Higgs potential allow for expressing μ and B_0 in terms of $\tan\beta = v_t/v_b$ and m_Z, and thus effectively reducing the minimum number of independent parameters to five. We take them to be: m_0, $m_{1/2}$, A_0, $\tan\beta$, and $m_t = h_t v_t$. (There is an additional two-fold ambiguity in choosing the sign of μ.) Since $\tan\beta$ can be large we also include h_b and h_τ. The parameters listed above determine the whole spectrum of masses and couplings in the model.

The considered framework is remarkably predictive. As an input from experiment we use only a few well measured quantities: m_Z, $\alpha_{\rm em}$, $\sin^2\theta_w(m_Z)$, and, in considering m_b, the mass of the tau lepton. Since evaluation is usually done in the $\overline{\rm MS}$-scheme, all these quantities must be 'translated' into the $\overline{\rm MS}$-scheme at specified energy scales.

By using the previously stated assumptions and the RG Equations (RGEs) one is then able to calculate $\alpha_{\rm s}(m_Z)$, m_b, and the masses of all the squarks, sleptons, Higgs bosons, gluinos, charginos, and the neutralinos in terms of a few basic parameters. One can then identify the lightest supersymmetric particle (LSP) and calculate its relic abundance. In addition we impose dynamical gauge symmetry breaking yielding the correct value of m_Z. Finally, for each point in the parameter space one can estimate the amount of fine-tuning needed to find phenomenologically interesting solutions.

We simultaneously evolve all the relevant parameters between the GUT scale and the electroweak scale and properly take into account the effect of multiple mass thresholds on the running of the gauge couplings. The details of the procedure can be found in Ref. [3]. I stress that we don't fix a single SUSY breaking scale at some arbitrary value but rather perform a global dynamical derivation of the low-energy mass spectra. We also avoid making *ab initio* such potentially questionable constraints on the parameter space as fixing the value of poorly measured α_s, requiring no fine-tuning, or assuming that $m_{\tilde{q}} \lesssim 1$ TeV. Instead, we display the effect of various constraints on the *output* of the analysis. This way we have a much better control of the meaning of our conclusions.

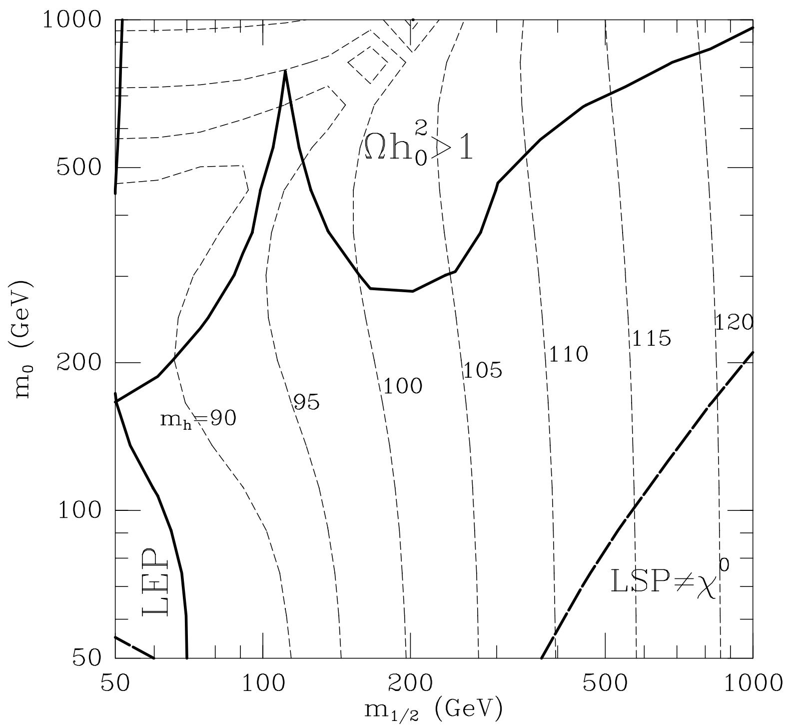

Figure 1. In the plane $(m_{1/2}, m_0)$ for $m_t = 160$ GeV, $\tan\beta = 5$, $A_0 = 3$, and $\mu > 0$ I present the mass contours of the Higgs boson h (short-dashed line, in GeV). Regions delineated by thick solid lines are excluded by: (a) high-energy experiments (marked LEP in the Figure) (In this case it comes from $m_{\chi^\pm} > 46$ GeV.); and (b) the conservative lower bound on the age of the Universe of 10 Gyrs (marked $\Omega h_0^2 > 1$). The region marked LSP $\neq \chi^0$ is not excluded but strongly disfavored by cosmology (see text).

I will now focus on the selected region of the parameter space. This is presented in Fig. 1 for $m_t = 160$ GeV, $\tan\beta = 5$, $A_0 = 3$, and $\mu > 0$. First, experimental constraints (in this case the most limiting being $m_{\chi^\pm} \gtrsim 46$ GeV, marked LEP) are at present extremely mild. Second, the very powerful cosmological constraint $\Omega h_0^2 < 1$ comes from a very conservative lower bound of about 10 billion years on the age of the Universe [4]. (It does not depend on the specific nature (nor even the existence) of dark matter.) The third constraint is not so firm: in the region marked 'LSP$\neq \chi^0$' the lightest neutralino is not the LSP. Instead, it is either a sneutrino leading to a very small relic abundance, $\Omega_{\tilde{\nu}} \sim 10^{-4}$, or charged/colored sparticle (either stau or stop). Both possibilities are strongly disfavored on cosmological grounds but not firmly excluded [4]. Finally, we somewhat arbitrarily limit $m_{1/2} < 1$ TeV (which, via Ωh_0^2, puts a similar bound on m_0). This corresponds to $m_{\tilde{g}} \lesssim 2$ TeV (and similarly for the squarks and heavy Higgs bosons). In the selected region $0.121 < \alpha_s(m_Z) < 0.131$ (decreasing slowly for $m_{1/2}, m_0$ above 1 TeV), in an excellent agreement with the experimental data [5]. (As I mentioned before, m_b comes out too large but the GUT-scale corrections are expected to be significant [3].) For other choices of parameters [3] the relative importance of these constraints varies, with the requirement of correct electroweak gauge symmetry breaking often playing also a significant rôle, but typically they all allow a broad region $m_0 \sim m_{1/2}$.

In Fig. 1 I also plot contours of the 1-loop-corrected Higgs boson mass m_h resulting from the analysis [3]. In the selected region we find $m_h \lesssim 120$ GeV and h is SM Higgs-like. It is clear that the discovery potential of LEP II will crucially depend on its beam energy [3]. If one can reach $\sqrt{s}$ above 200 GeV then a significant range of m_h can be explored. In contrast, chances of the Higgs discovery are less than slim for $\sqrt{s}$ in the currently approved range of about 176 GeV, for which m_h can be searched up to about 80 GeV [6]. It is also clear that the NLC with even a modest choice of $\sqrt{s} = 300$ GeV will cover the whole Higgs mass range in the expected region of $m_{1/2}$ and m_0 [3]. These conclusions apply also to other choices of parameters. More detailed studies are needed to determine more precisely what regions of the plane $m_{1/2}, m_0$ will be covered by Higgs searches as a function of $\sqrt{s}$ and luminosity.

Finally, I briefly mention about prospect for other SUSY particles searches in this model [3]. A priori they could be discovered even at LEP II and the Tevatron. However, requiring the LSP to be the dominant component of (dark) matter in the Universe puts *lower* limits on their masses making their discovery unlikely before the next generation of supercolliders (SSC and LHC) and e^+e^- linear colliders (NLC with $\sqrt{s} = 500 - 1000$ GeV) [2, 3]. If so, then finding the lightest Higgs may be our window of opportunity for confirming supersymmetry before the next millennium, in fact in just a few years.

Acknowledgments

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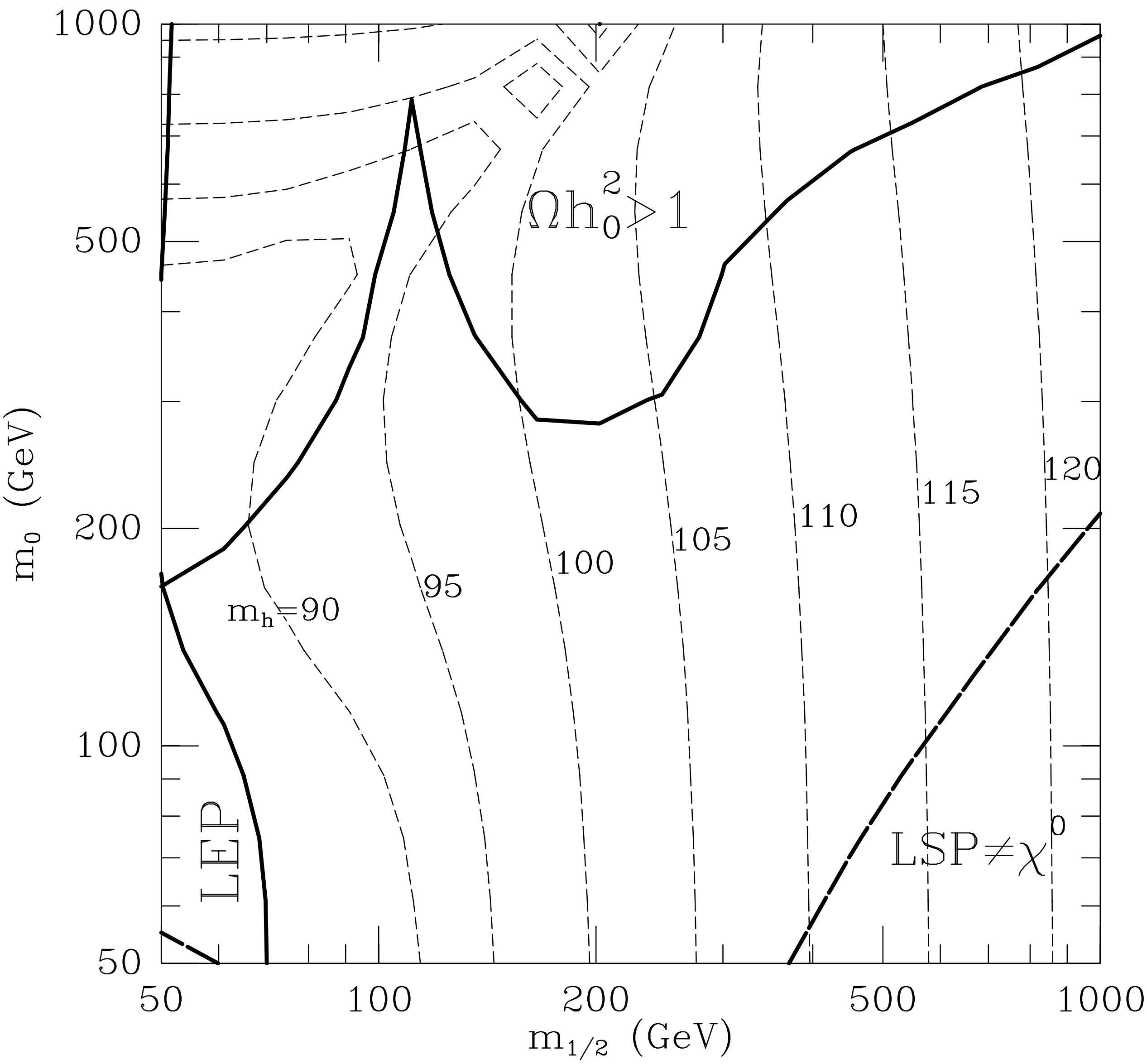

1000
500
200
100
50
50
100
200
500
1000
m_0 (GeV)
$m_{1/2}$ (GeV)
$\Omega h_0^2 > 1$
m_h=90
95
100
105
110
115
120
LEP
LSP≠χ^0